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Successful Recovery and Decommissioning of Russian RTGs
– A Cooperative International Effort

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ABSTRACT

From the 1970s into the early 1990s the Soviet Union and subsequently the Russian Federation actively used Radioisotope Thermoelectric Generators (RTGs) as sources of energy for lighthouses, navigation beacons, and other remote monitoring sites requiring autonomous power. By the end of the century over a thousand RTGs had been deployed. An RTG transforms heat through thermoelectric conversion into electric power, where the source of heat is generated through natural linear decay of radioactive isotopes (strontium-90). Most of these RTGs were installed at unguarded remote sites, but others were deployed near population centers. Recognizing the risk posed by the theft of unattended RTGs and their radioactive sources, Russia, the United States, and others within the international community agreed that something needed to be done to reduce the threat in the near term; while ultimately planning to fully recover and dispose of all RTGs, most of which had already exceeded their service life. The DOE/NNSA, Lawrence Livermore National Laboratory, Rosatom, and the NRC Kurchatov Institute led the effort, with expertise provided by other scientific U.S. and Russian organizations, as well as assistance from Norway, Canada, Finland, and France. In 2007 a Master Plan was developed and approved by Rosatom to address the overall complex task of recovering RTGs from largely remote geographical locations, transporting them to temporary storage, or directly to disassembly facilities; while remote security monitoring was recommended for those RTGs that posed even a higher risk (e.g. near population centers). Equally complex was the disassembly process, given the age of the RTGs and unforeseen issues when extracting RHSs (Radioactive Heat Sources), as well as the security risks when transporting sources to a long-term storage location for final disposition. In 2008, an Action Plan was initiated to carry out the Master Plan directives to best allocate resources and avoid duplication of effort. The results of the international effort have been hugely successful, where over the past decade 98% of the RTGs have been recovered, and alternative power sources (APS) based on solar energy replaced many of the active RTGs.

History of Russian RTGs

From the 1970s through the 1990s the Soviet Union, and subsequently the Russian Federation, actively used radioisotope thermoelectric generators (RTGs) as energy sources for lighthouses, navigation beacons, and other remote monitoring sites that required an autonomous source of power. These RTGs used radioactive Strontium-90 (Sr-90) as the primary source of thermal energy, which was then converted into electricity by thermoelectric converters. The RTG itself contained one or more stainless-steel capsules housing the radioactive heat sources (RHSs). The radioactivity of the manufactured RTGs was very high, as the higher the activity of the Sr-90 source the greater the amount of heat was released during decay, and therefore a greater amount of electricity was produced. For example, the initial activity of Sr-90 in an IEU-1 (the highest-capacity RTG) was 465,000 curies (Ci) or ~1.72 x 10E+16 becquerels (Bq). According to source passport data, the initial activity of various RTG models had the following values[1]:

Type of RTG	Sr-90 activity, kCi	Sr-90 activity, Bq
IEU-1	465	1.72E+16
Gorn	173.24	6.40E+15
IEU-2M	116.25	4.30E+15
Efir-MA	104.45	3.86E+15
IEU-2	100.75	3.73E+15
Gong	46.5	1.72E+15
Beta-M	35.7	1.32E+15

By comparison, the radioactivity of one nuclear submarine with spent nuclear fuel measures approximately 270.3 kCi[2]. The design of the RTG provides protection against environmental factors and includes biological shielding to protect people from radiation exposure.

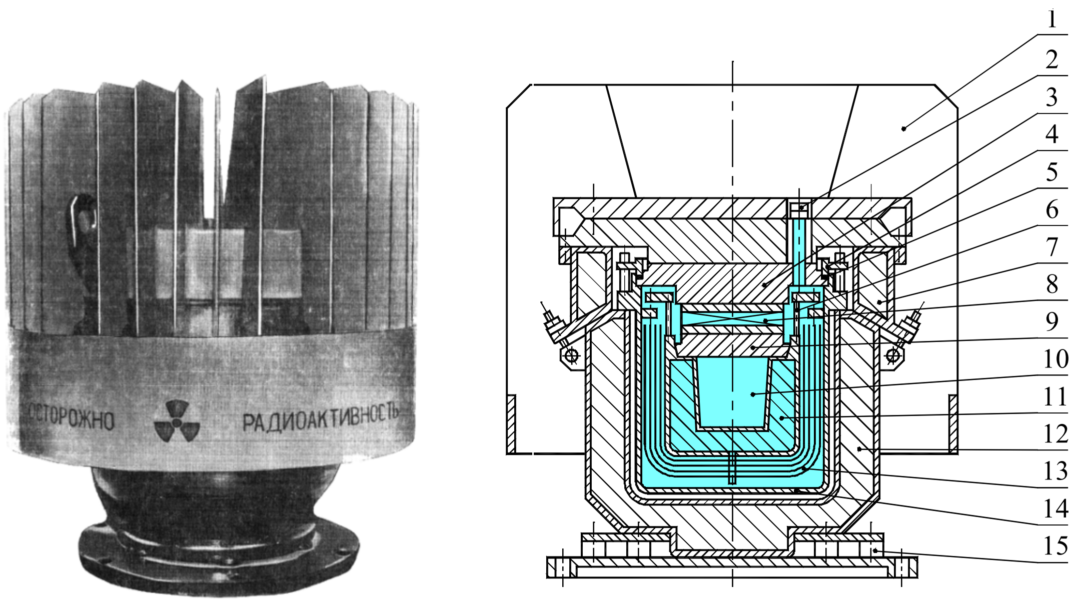

Fig.1. External view and cross-section of a Beta-M RTG[3]:

1—radiator; 2—electrical lead; 3—lid; 4—flange; 5—lining; 6—radiation source support; 7—radiation shielding; 8—thermoelectric unit; 9—lid; 10—heat source; 11—protective unit; 12—radiation shielding; 13—screens; 14—housing; 15—base

In total, there were approximately 1,015[4] Sr-90-based RTGs manufactured in Russia (NIITFA) and Estonia (Baltiest) that were used as power sources in land-based applications. Russian radioisotope thermoelectric generators had a service life of at least 10 years, according to their passport data. Often this service life was extended by the manufacturer after confirmation the unit was still operational, which could prolong the service life to 15-20 years or even longer in some cases. The decision was made in the early 2000s to decommission the RTGs, as these devices with their high activity radioactive sources were not only an environmental concern; they also posed a security threat, since the material that powered them could be used in a radiological dispersal device (RDD) or ‘dirty bomb’. Over the years, there were some reported cases of vandalism and unauthorized activity to dismantle RTGs, though primarily for the non-radioactive components and materials. This raised concerns that the Sr-90 sources might be extracted from the RTGs and used for malicious purposes. The autonomous operation of RTGs was originally viewed as a benefit; however, it later became apparent it was more of a liability as it provided relatively unfettered and undetected access to radioactive sources. Efforts to decommission RTGs were delayed by a number of factors, including the lack of necessary financing and the need to replace them with reliable, low-maintenance alternative power sources.

International Involvement

The International Atomic Energy Agency (IAEA) Contact Expert Group (CEG) held a meeting in Oslo, Norway in 2005 entitled “Security and Safety of Radioactive Sources: Decommissioning and Replacement of Radioisotope Thermoelectric Generators”. Though several countries had already started assisting with the effort, areas of responsibility were defined for donor countries. The location of RTGs both in the field and in storage at the time of the 2005 conference is shown in Figure 2.

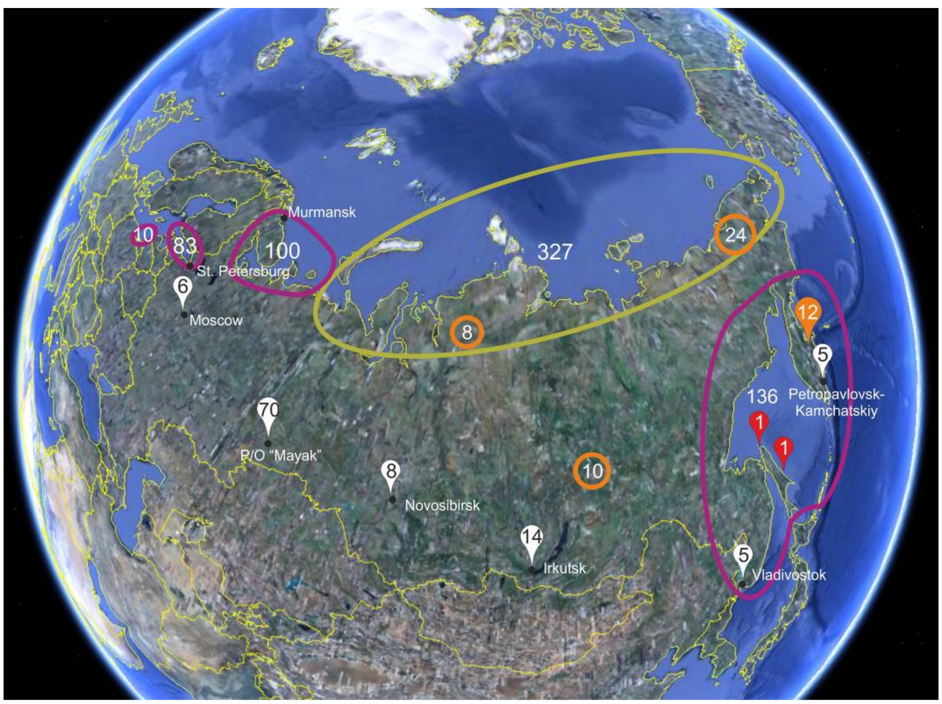

Fig.2. Locations of RTGs still in the field on the Russian territory in 2005

- *RTGs Awaiting Recovery (circled): Gold–Owned by Ministry of Transport; Purple –Owned by Navy; Orange–Owned by Ministry of Defense*
- *RTGs in Storage: White background*
- *RTGs that were lost: Red background (1 was later found)*
- *RTGs in operation: Orange background*
- *4 RTGs in Antarctica – not shown*

Later the IAEA established an International Coordination Working Group (ICWG) on RTGs, with Russia serving as the chairman and the U.S. as the co-chairman. For many years the ICWG consisted of representatives from donor countries (i.e. Norway, France, Finland, Sweden, Canada, and the U.S) along with numerous Russian government agencies, organizations, and oversight authorities. The purpose of this group was to help ensure RTG efforts were not duplicated by the involved parties while leveraging strengths of each. The ICWG discussed all aspects of RTG work such as assessing risk, environmental impacts, transportation routes, temporary storage facilities, and project plans. Later, the ICWG consisted solely of Russian and American representatives, as other donor countries completed their RTG projects in Russia. From the beginning of the ICWG, NRC Kurchatov Institute has played the lead role in coordinating RTG activities among Russian and international organizations.

Russian-Norwegian/ Finland Effort

During the period 2001-2014, and within the framework of Russian-Norwegian cooperation in the Northwest of Russia, numerous radiologically hazardous RTGs were removed and decommissioned. RTGs were removed from the coastline and islands of the Barents, Kara and White Sea, as well as in the territory of Murmansk Oblast (Region) and other regions in the Norwest Federal District, to include Arkhangelsk Oblast, Nenets Autonomous Okrug, and the Republic of Karelia. RTGs were also removed along the coastline and islands of the Baltic Sea in Kaliningrad and Leningrad Oblasts. Where applicable, Finland also provided their support.

A total of 251 RTGs have been removed from the coastline and islands of the Barents, White, Kara (including Novaya Zemlya Archipelago) and Baltic seas and disposed of. This included 85 RTGs from the territory of Murmansk Oblast (Barents Sea), 68 RTGs from the territory of Arkhangelsk Oblast and Republic of Karelia (White Sea), 27 RTGs from the territory of Nenets Autonomous Okrug / coastline and islands, 63 RTGs from the territory of Leningrad Oblast / islands and coastline of Gulf of Finland, and 8 RTGs from the Baltic coast of Kaliningrad Oblast. Moreover, for those sites that still needed autonomous power, alternative power sources (APS) based on solar energy have been installed for powering the navigation equipment. Under the Russian-Norwegian project, 229 APSs were installed, including 56 lighthouses and navigation stations in the Baltic Sea.

Russian-American RTG Effort

The United States of America met with the Russian Federation early in 2002 to discuss initiating a program to address the issue of RTGs in the field, their recovery, and decommissioning. In 2003 an agreement was signed to recover Ministry of Transport RTGs, located primarily at navigational beacons along the Northern Sea Route. In addition, during the early years of cooperation, the U.S. funded security upgrades at sites where RTGs had been dismantled. At a technical seminar in 2003 Admiral Nikolai Yurasov declared there was also a problem with Russian Federation Navy RTGs, which expanded the discussion and scope of work to include RTGs in the Far East and the Baltics. All parties agreed the RTGs posed a security issue and environmental concern and the fact they had already exceeded their service life. Therefore, in order to reduce the threat of RHSs being stolen and used for malicious purposes, they needed to be removed and replaced with alternative power sources (APS) where needed. Over the years, numerous Russian and American entities have been involved in the challenging yet important process of decommissioning RTGs. The effort consisted of removing the RTGs from the field, disassembling the devices, disposing of the radioactive heat sources, and often replacing the units with alternative power sources. All RTG activities conducted by the U.S. were financed and implemented by the U.S. Department of Energy, National Nuclear Security Administration's

Global Threat Reduction Initiative (GTRI), now known as the Global Material Security/ Office of Radiological Security (GMS/ORS). Over a decade of cooperation between the U.S. and Russia resulted in the successful decommissioning of RTGs from the Northern Sea Route, the Russian Far East, the Baltic Sea region, and other devices owned by the Ministry of Defense.

The result of over a decade of cooperation between the USA and Russia was the successful decommissioning of RTGs from sites on the Northern Sea Route, in the Far East and in the Baltic Sea region, and from sites belonging to the Ministry of Defense of Russia and located outside the coastal area in the continental part of Russia. The result of Russian-American cooperation over the past decade was the successful evacuation of 486 RTGs. In addition 295 APSs were manufactured, with over 220 deployed at select operating sites. The Russian-American program also included the construction of several storage facilities at sites in the Russian Far East managed by DalRAO.

Russian-French RTG Effort

Cooperation between Russia and France in the area of RTG decommissioning began in 2009 and ended in 2012. All RTG work was financed and implemented by the French Atomic Energy Commission. The result of this cooperation was the successful decommissioning of 14 RTGs from sites in the Baltic Sea region. Alternative power sources were installed at 12 sites that still needed autonomous power in the Gulf of Finland and Baltic Sea. This included two of the most powerful APS replacements, where in addition to solar photovoltaic power, also employed wind generators. All of the APS continue to operate successfully.

RTG Decommissioning Process

Prior to initiating operations to recover RTGs, Russian technical specialists conducted surveys of each RTG in the field to assess the condition of the device and determine if it could be certified

Fig.3. Lifecycle of an RTG removal, disassembly and disposal of sources

for transport. Upon making the determination and obtaining the necessary authorizations and transportation certificates, the actual removal work began. Often RTGs were moved to local consolidation points before being transferred to either an interim secure storage site or to a disassembly facility. Once RTGs were disassembled the radioactive heat sources were sent to the Federal State Unitary Enterprise (FSUE) Mayak Production Association for long-term storage. The RTG decommissioning process is depicted in Figure 3.

Ministry of Defense RTGs

In 2003, the Department of Navigation and Oceanography of the Russian Navy, together with the National Research Center (NRC) Kurchatov Institute conducted a technical seminar with American and Russian specialists. The main goals of this seminar were to discuss the protection of Russian Navy radioactive sources, develop a preliminary assessment of source vulnerability, and initiate the development of an RTG inventory. In the same year, work began on analyzing APS replacements for the RTGs.

From 2004 to 2006 the U.S. and Russia worked on pilot projects in the Baltic region and Far East where several RTGs were removed and replaced with APS units. These pilot projects included replacement power systems manufactured by Joint Stock Company (JSC) Saturn. Later in the program, NRC Kurchatov Institute also designed and manufactured APSs that included LED lamps (as replacements for inefficient incandescent lamps) for sites in the Russian Far East areas of Primorye, Soviet Gavan, Sakhalin Island, Kuril Islands, Kamchatka, and Magadan.

Between 2004 and 2006, NRC Kurchatov Institute oversaw the construction and commissioning of a temporary storage facility called DalRAO 1 located in Primorskiy Kray in the Far East. It was designed to store up to 250 decommissioned RTGs for a period of up to 50 years. The DalRAO 1 storage facility is located in a secure area measuring approximately 4,000 square meters and includes a building for storing RTGs, a checkpoint building, and necessary infrastructure (reference Figure 3). The majority of the RTGs that were recovered from the Far East under the U.S.-Russia cooperative program were transported to this facility for secure storage.

When the U.S. first got involved in RTG recovery work there were 194 RTGs located in the Far East: 182 RTGs were in operation, 10 RTGs were in temporary storage, and 2 RTGs were considered lost (one of them was subsequently found and is currently at Soviet Gavan). Between 2005 and 2009, the U.S. and Russia worked to decommission 134 RTGs and transport them to the DalRAO 1 storage facility. Subsequently, 108 sites received APS replacements. Canadian funding supported the recovery of 39 of these RTGs in the Far East.

During the period between 2008 and 2009, NRC Kurchatov Institute, with U.S. support, recovered 34 RTGs belonging to the Ministry of Defense from the Russian mainland. Ten were Gorn RTGs removed from the town of Peleduy and transported by motor vehicle to the DalRAO 1 storage facility. In addition, there were 24 Beta-M RTGs transported by an IL-76 aircraft from Bilibino and delivered to JSC National Technical Physics and Automation Research Institute (NIITFA) for disassembly.

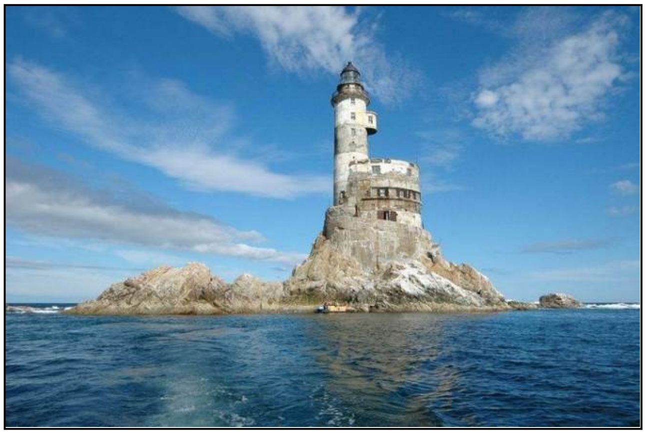

Fig.4. Aniva site in Primorye Region, where 3 RTGs were removed and an APS was installed

Fig.5. Close up of the solar panel installation at the Aniva site

When the U.S. and Russia completed efforts to recover RTGs in the Far East in 2009, the DalRAO 1 storage facility housed 156 RTGs, including some RTGs that had been recovered using Russian funding. The long-term storage of RTGs came with some risks due to potential degradation of the depleted uranium shielding, causing oxidation, and subsequent radioactive contamination. Therefore, from 2009 to the present the U.S. has been working with JSC NIITFA and JSC Isotope to transport RTGs from DalRAO 1 to facilities for disassembly and long-term source storage at Mayak. Currently, 94 RTGs remain at the storage facility. Work to remove most of the remaining RTGs at DalRAO 1 is scheduled to continue over the next few years.

Concurrent with the aforementioned activities (2005-2009), NRC Kurchatov Institute, with financial support from the U.S., developed and installed a monitoring system for 79 RTGs in the Baltic region. The RTG sites were selected since they were close to population centers and there was no immediate plan for the removal of the RTGs. The monitoring system made it possible to mitigate unauthorized access or theft of the RTGs in the Baltic region before plans could be made for their removal. All the RTGs in the Baltic region were removed by 2011, at which time the monitoring system was no longer needed.

Ministry of Transport and Roshydromet RTGs

During the period from 2004 to 2009 removal and recovery efforts of RTGs located along the Northern Sea Route and the Yenisei River was implemented by JSC NIITFA, using U.S. and Canadian financial support. During this period, 127 RTGs were removed from the Northern Sea Route (20 using Canadian funding), and 48 APS units were installed at select sites. JSC Technomarine designed and manufactured the APSs for these remote locations located near and within the Arctic Circle. The power sources, based almost exclusively on solar technology, required special components, including batteries filled with Arctic-rated electrolyte to withstand the severe weather conditions.

In 2009, NRC Kurchatov Institute with support from other Russian organizations FSUE Hydrographic Enterprise of the Ministry of Transport and JSC Pacific Construction and Production Company (TSPK) began work to survey and remove RTGs from navigational beacon sites located along the eastern and central parts of the Northern Sea Route. Beginning in the

Chukotka region, RTG removals and APS replacement installations commenced from east to west, with the final removals taking place in 2013 from the Taimyr and Yamal peninsulas. The aviation companies Chukotavia and Taimyr played a key role in the transport and consolidation of the RTGs along the Northern Sea Route. In total, NRC Kurchatov Institute was instrumental in facilitating the removal of 184 RTGs from this region.

Logistics and Challenges of RTG Decommissioning

Logistics used for the removal and transport of RTGs varied greatly depending on geography, climate, certification, cost effectiveness, and other criteria. The same could be said for the delivery of APS equipment and personnel. Trucks were modified to endure the harsh climate and terrain conditions, while the long haul transport vehicles were equipped with security systems. Small tractors and vessels (e.g. self-propelled barges) were also used for short distances to ships or consolidation points. Helicopters were used extensively, particularly in remote areas, for short and medium haul trips. For long distances, transport planes (e.g. IL-76) were used to carry Beta-M RTGs, while hydrographic vessels were used to transport heavier RTGs. Motor vehicle convoys and in some cases trains were used to transport RTGs from collection points to interim storage locations, or directly to Rosatom facilities for disassembly.

Fig.6. RTG being loaded in Baltics as part of Norwegian assistance

Fig.7. RTG being transported by helicopter in sling

There were many challenges to the recovery, replacement, disassembly, and disposal of RTGs, all of which had an effect on the cost and schedule for completing the work. Many of the RTGs in Russia were located in remote locations with harsh climates (e.g. islands, peninsulas, and along rugged coast lines). Inclement weather was a constant challenge, as were frozen seaways and competing demands for local contractors and equipment. The RTG work was made more difficult as these locations required recovery operations during limited spring or fall months due to weather conditions (e.g. heavy fog in the summer and limited light in the winter). In addition, some of the coastal installations were located in nature preserve areas that also had restricted access during certain times of the year in order to protect the local wildlife. Transportation of RTGs was also a challenge. Moving units from their remote locations required extensive physical exertion, technical expertise, and tolerance of hardship in rough terrain. This intensive work was accomplished by dedicated Russian teams that used innovative methods to ensure safe removal of the RTGs.

Antarctica Project

As part of the international cooperative effort, it was decided to repatriate the RTGs from Antarctica back to the Russian Federation for disassembly and final disposition. Because most of the international and Russian laws were written for countries, and Antarctica is a continent with special international status under the Treaty of Antarctica, the legal preparation and obtaining the necessary licenses and permissions was exhaustive and complex. Moreover, approvals for ports of call and crossing territorial waters with equipment housing radiological material also presented numerous challenges. Of the remaining RTGs to be recovered one (1) was located far within the interior of Antarctica and had become buried deep into the ice pack. This required a special expedition consisting of trained subject matter experts from various Russian entities, and special technologies, such as ground penetrating radar, ice cutting equipment, and retrofitted vehicles to transport the RTG back to one of the coastal stations. The RTG was then loaded by helicopter onto a ship with the other RTGs. It was a true cost-sharing effort as the Russians provided the use of one of their ships to repatriate the RTGs back to Russia, while the US funded retrofits to the ship, training, equipment, and other related activities.

Figure 8. Expedition en route to the interior of Antarctica to recover RTG at Dome B

Figure 9. Airlifting RTG onto Academik Fedorov at Novolazarevskaya station

Accomplishments

Working with the international community numerous Russian government organizations and companies contributed to the success of this cooperative program, including but not limited to NRC Kurchatov Institute, JSC NIITFA, JSC Isotope, FSUE Hydrographic Enterprise, the Russian Navy, the 12th Main Directorate of the Russian Ministry of Defense, State Atomic Energy Corporation "Rosatom", Rostekhnadzor, JSC Pacific Construction and Production Company (TSPK), JSC Technomarine, Mayak Production Association, RosRAO, Chukotavia, Taymir, Atomspectrans, and Volga Dnepr.

International engagement involved experts from Lawrence Livermore National Laboratory, Sandia National Laboratory, Nevada National Security Site and Argonne National Laboratory, and Oak Ridge National Laboratory, the National Nuclear Security Administration (NNSA) / US Department of Energy, the Norwegian Radiation Protection Authority (NRPA), Finnmark Court Municipality (Norway), French Alternative Energies and Atomic Energy Commission (CEA), and the International Atomic Energy Agency Contact Expert Group.

Over the past decade with the assistance of the international community, 751 RTGs were successfully recovered, and 536 APS units were manufactured. Russia searched for and located two (2) RTGs that were lost along the Northern Sea Route, leaving only one that is still lost at sea by Sakhalin Island which the Russian Federation will continue to search for. Figure 10 shows the remaining RTG locations. By decommissioning 751 RTGs, hundreds of Sr-90 sources have been disposed of, resulting in more than 30 million Ci of vulnerable radiological material now secured. The success of this joint program is a testament to the dedication, professionalism, and strong working relationship between the two countries and the many entities involved. The U.S. and Russia will continue to work together in the near future to identify potential areas of cooperation to address any remaining RTG issues.

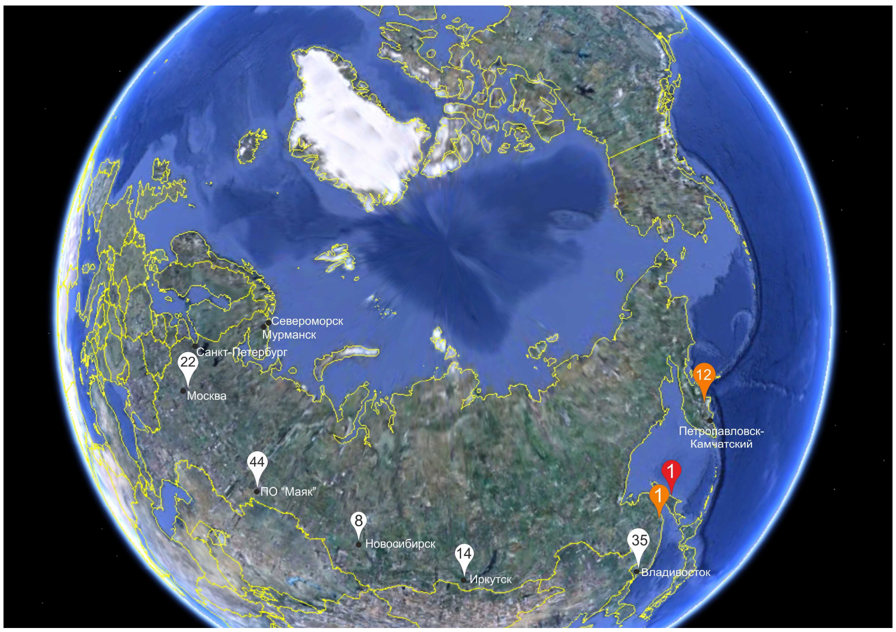

Figure 10. Location of remaining RTGs - 2016

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